U. S. DEPARTMENT OF COMMERCE

BUILDING MATERIALS AND STRUCTURES

REPORT BMS83

Strength of Sleeve Joints in Copper Tubing Made With Various Lead-Base Solders

by

ARTHUR R. MAUPIN
and WILLIAM H. SWANGER

NATIONAL
BUREAU OF STANDARDS

The program of Research on Building Materials and Structures, carried on by the National Bureau of Standards, was undertaken with the assistance of the Central Housing Committee, an informal organization of governmental agencies concerned with housing construction and finance, which is cooperating in the investigations through a committee of principal technicians.

The Forest Products Laboratory of the Forest Service is cooperating with both committees on investigations of wood constructions.

[For list of BMS publications and directions for purchasing, see cover page III]

UNITED STATES DEPARTMENT OF COMMERCE · Jesse H. Jones, Secretary

NATIONAL BUREAU OF STANDARDS · Lyman J. Briggs, Director

BUILDING MATERIALS *and* STRUCTURES

REPORT BMS83

Strength of Sleeve Joints in Copper Tubing Made With Various Lead-Base Solders

by

ARTHUR R. MAUPIN *and* WILLIAM H. SWANGER

ISSUED MAY 5, 1942

The National Bureau of Standards is a fact-finding organization; it does not "approve" any particular material or method of construction. The technical findings in this series of reports are to be construed accordingly.

UNITED STATES GOVERNMENT PRINTING OFFICE · WASHINGTON · 1942

FOR SALE BY THE SUPERINTENDENT OF DOCUMENTS, WASHINGTON, D. C. · PRICE 10 CENTS

Foreword

In report BMS58, Strength of Soft-Soldered Joints in Copper Tubing, mention was made in the foreword of an additional paper to present results obtained with other less commonly used soft solders. The solders referred to are lead-base alloys with little or no tin content. The presentation in this paper of information on the practicability of using such solders and of data on the strength and temperature limitations of joints made with them is believed to be of timely interest.

LYMAN J. BRIGGS, *Director.*

Strength of Sleeve Joints in Copper Tubing Made with Various Lead-Base Solders

by ARTHUR R. MAUPIN *and* WILLIAM H. SWANGER

CONTENTS

ABSTRACT

A previous investigation on soft-soldered sleeve joints in copper tubing for domestic plumbing lines and other uses dealt with joints made with two tin-base solders. To supplement that investigation, the present one on similar joints made with various lead-base solders was conducted. Solders of the following types were used: lead-silver, lead-tin-antimony, lead-cadmium, high lead–low tin, and high-purity lead. Tensile tests at room temperature (short-time tests) were made, together with long-time tests at temperatures ranging from 85° to 325° F. The information from the latter tests is much more useful than the results of short-time tests in evaluating soldered joints for service. Consideration must always be given also to possible bond deterioration of the soldered joint at elevated temperatures. On the basis of the results of the first investigation, joints in copper made with tin-base solders were considered satisfactory for general use, provided the temperature did not exceed 250° F. The results of the present study have shown that similar joints made with lead-base tin-free solders can be used with safety at temperatures as high as 325° F.

I. INTRODUCTION

In the report of a previous investigation [1],[1] the apparatus, materials, method used for testing, and the results of tests on sleeve joints in copper tubing made with (50–50) tin-lead solder and with (95–5) tin-antimony solder were discussed. In the present paper are summarized the results obtained by the same procedure on similar sleeve joints made with a variety of lead-base soft solders.

The (50–50) tin-lead and the (95–5) tin-antimony solders used in the previous study meet the general needs of domestic plumbing satisfactorily, and, in addition, the (95–5) tin-antimony alloy is a satisfactory soft solder in certain other applications where the presence of lead is not desired. These two solders were not found satisfactory, however, for service conditions in which the temperature exceeded 250° F. Hence the investigation was continued in hope of finding a soft solder that would be satisfactory for service at a temperature as high as 325° F. Also, the turn of events during the time the investigation was in progress indicated that more specific information on the strength properties and limitations of lead-base soft-solder alloys with little or no tin content might be of considerable industrial importance. In this investigation, promising alloys already known were used and no effort was made to develop new ones.

II. MATERIALS

1. Tubing

The materials used in the construction of the joints have been described in the previous publication [1]. Suitable lengths of type *L* hard-drawn copper tubing, ¾-inch diameter, soldered into wrought-copper couplings (straight sleeve fittings) were used in all of the long-time tests.

[1] Figures in brackets refer to literature references listed at the end of the report.

446484°—42

In a short-time tensile test (speed of 0.06 inch per minute of the movable head of the testing machine) the load to cause rupture in a soft-soldered joint is much greater than is required in a long-time test of the same kind of joint under a constant load. In the short-time test, the loads to cause rupture in the joints, with most of the solders in table 1, exceeded the strength of types *K* and *L* tubing and of the wrought-copper couplings. To insure occurrence of the failure within the soldered joints, the specimens were made by soldering suitable lengths of solid copper rod into straight sleeves of iron-pipe-size copper tubing. The clearance between rod and sleeve was the same as in the coupling used in the long-time tests.

2. Solders

All of the solders used were of the lead-base type and are listed in table 1 with information on their composition and the temperature interval within which melting occurs.

Table 1.—*Composition and melting ranges of solders, and maximum shear strength on soldered areas of joints made therefrom*

Nominal composition						Melting range (approx.)	Maximum shear stress at room temperature (Approx. 85° F), short-time test [a]
Lead	Tin	Silver	Cadmium	Zinc	Antimony		
%	%	%	%	%	%	° F	lb/in.²
95	5	------	------	------	------	575 to 595	3,000
60	39	------	------	------	1	360 to 430	5,700
95.3	------	4.7	------	------	------	580 to 670	2,900
97.2	------	2.8	------	------	------	580 to 595	2,900
85.4	------	------	14.3	0.3	------	475 to 485	6,000
82	------	------	17.5	.5	------	477	6,000
[b] 100	------	------	------	------	------	621	1,800
[c] 50	[c] 50	------	------	------	------	[c] 360 to 420	[c] 5,500
------	[c] 95	------	------	------	[c] 5	[c] 450 to 465	[c] 6,200

[a] A sleeve-type joint formed by soldering a solid rod of copper into ⅝-inch iron-pipe-size copper tubing was ruptured in a tensile-testing machine, the loading rate corresponding to 0.06 inch per minute rate of travel of the movable head.
[b] Total impurities not exceeding 0.02 percent.
[c] Included from previous investigation.

III. TESTING PROCEDURE AND RESULTS

The precautions observed in making the soldered sleeve joints were identical with those previously described. In order to insure uniformity in the dimensions of the solder film in the various joints, the bore depth in the joint was maintained at 0.87 ±0.01 inch and the diametral clearance at 0.004 ±0.0006 inch.

1. Short-Time Tensile Tests

The testing procedure did not differ in any essential respects from that described in the previous report [1]. The results are summarized in table 1. The corresponding results obtained in the previous investigation with tin-rich solders are also given in table 1.

2. Long-Time Loading Tests

The sleeve-joint specimens were made, as in the previous investigation, by soldering two lengths (approximately 15 inches, each) of type *L*, hard-drawn copper tubing, ¾-inch nominal size, into commercial wrought-copper couplings. These were loaded in tension by means of weights and a lever device. For the elevated-temperature tests, the central portion of the specimen, approximately 8 inches long, containing the joint was surrounded by the heating device, the cylindrical wall of which was of Pyrex glass, which permitted observations to be made on the gage marks used for measuring extension, without removing the heating unit.

In general, for each type of solder, four specimens, maintained at the same temperature, were subjected to loads ranging, at approximately equal spacing, from one estimated to be considerably below the maximum safe load to one considerably above the maximum safe load. After the maximum safe load had been determined approximately, other specimens loaded at closer intervals to this value were added so as to obtain a more accurate determination of the maximum safe load.

The maximum safe shear stress, as reported here, was obtained by dividing the maximum safe load by the soldered cylindrical area in the joint (not the cross-sectional area of the solder film).

The behavior of the various soldered joints at the different temperatures used, 85°, 250°, and 325° F, is summarized in table 2. Maximum shear-stress–temperature curves are also given in figure 1. The behavior of the individual joints made with the various solders when subjected to different loads at the three temperatures used is summarized in the appendix.

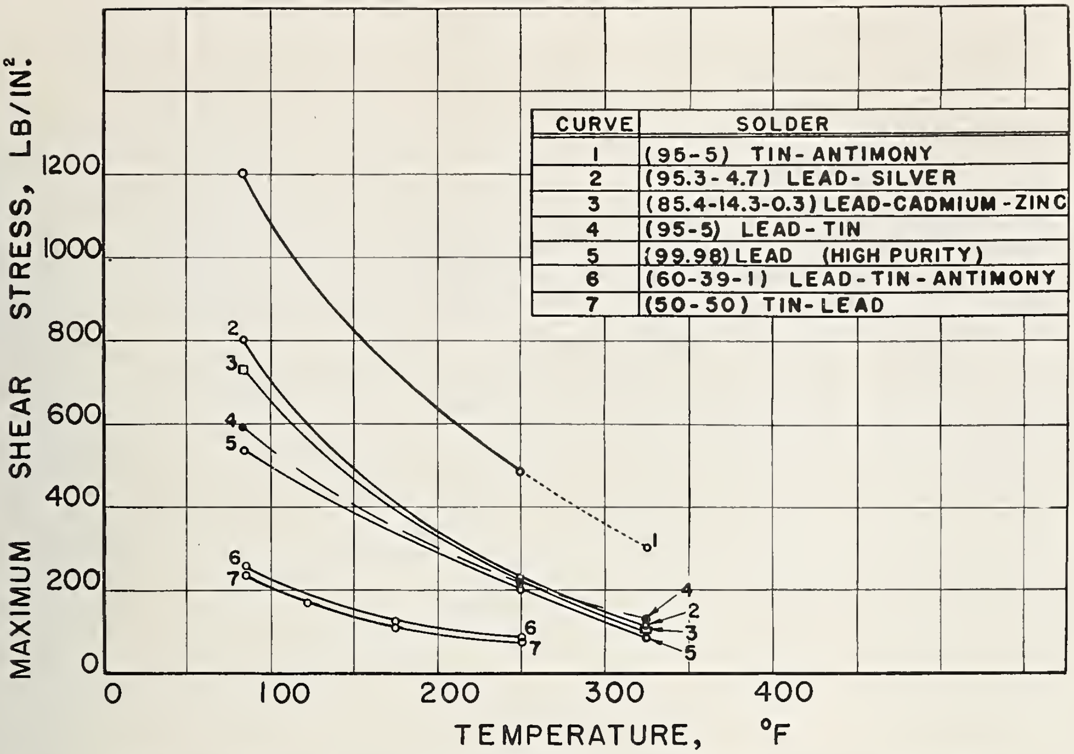

FIGURE 1.—*Maximum shear-stress–temperature relationships for sleeve joints in copper-tube lines, made with the solders listed in table 1.*

TABLE 2.—*Maximum allowable shear stresses at various temperatures in sleeve joints formed by soldering ¾-inch copper tubing (type L) into copper couplings*

Nominal composition of solder						Maximum allowable shear stress [c]		
Lead	Tin	Silver	Cad-mium	Zinc	Anti-mony	Room temperature, approx. 85° F	250° F	325° F
%	%	%	%	%	%	*lb/in.²*	*lb/in.²*	*lb/in.²*
95	5					590	215	160
60	39				1	260	90	(d)
95.3		4.7				800	220	105
97.2		2.8				800	220	105
85.4			14.3	0.3		740	(d)	90
82			17.5	.5		740	(d)	90
[a]100						535	200	85
[b] 50	[b] 50					[b] 235	[b] 80	(d)
	[b] 95				[b] 5	[b] 1,200	[b] 380	[b] 275

[a] Total impurities not exceeding 0.02 percent.
[b] Included from previous investigation.
[c] The joint was stressed continuously for 5,000 hours or more without failure.
[d] Not tested.

IV. DISCUSSION

The values for the short-time strengths in table 1 are useful to indicate the area in a joint that, when placed in pure shear, is necessary to withstand a given load, applied momentarily. If the joint is loaded so that the stress on the soldered area is not pure shear, a much lower value may be obtained for the strength of the joint; the magnitude of this difference depends upon the distribution between tensile stress across the solder film and shear stress within the film.

A more important index of the strength value of soft-soldered joints is that obtained under long-continued loading at a constant shear stress. Results of long-time tests, such as are given in table 2, are necessary to evaluate correctly the strength of soft-soldered joints at room or at elevated temperatures As the temperature of the joint was increased above 85° F, the strength decreased rapidly. The values in table 2 were obtained on sleeve joints between copper tubing and wrought-copper couplings, maintained under constant tensile loads, at 85°, 250°, and 325° F, for 5,000 hours or more. The values were calculated as shear stress on the soldered, cylindrical, area in the joint and are the maximum stresses at which extensions in the joints, indicating eventual failure, did not occur.

As will be shown later, however, maintenance

of strength at any specific temperature is not the only criterion to be used in evaluating a solder for service at that temperature. Permanence of the "bond" must also receive consideration.

In the previous investigation it was shown that at 250° F and upward, rapid deterioration of the bond between copper- and tin-alloy solders takes place; hence tin-alloy solders on copper are not satisfactory for continued exposure at 250° F and above. The same behavior was observed for the two solders containing tin used in the present investigation. Bond deterioration at 250° and 325° F was not observed between copper and the lead-silver, the lead-cadmium-zinc, or the pure-lead solders. Within the strength limitations given in table 2, these solders are therefore considered to be superior to any of the tin-alloy solders for use at temperatures of 250° F and above.

Pure lead can be used as a solder on a number of ferrous and nonferrous metals, but the technique for applying it is difficult and its use industrially can hardly be considered practicable. Moreover, the strength of joints made with pure lead is considerably lower than that of joints made with the solders of high lead content, which have the added advantage of possessing much better soldering properties.

Lead-silver alloys, with the silver content ranging from 2½ to 5 percent, have been used successfully. Failures that were encountered can reasonably be attributed to improper technique in applying them, or to the failure to recognize their strength limitations at elevated temperatures (table 2).

The lead-silver alloy containing 2.5 percent of silver is close to the lead-silver eutectic composition and is very fluid when melted. but the temperature interval over which it remains molten is relatively short. Hence it is not so suitable for "sweat" soldering as the alloy of higher silver content which was used. The upper limit of the melting range of (95–5) lead-silver alloy is about 670° F, which is rather high for some purposes. The zinc chloride flux, which must be used with this solder, deteriorates very rapidly at this temperature. The strength properties of the two lead-silver solders did not differ significantly. Probably (96–4) lead-silver alloy would be the most satisfactory proportions in a lead-silver soft solder, cost and other factors being taken into consideration.

The lead-cadmium-zinc solders are completely molten at temperatures well within the temperature range satisfactory for soft soldering with zinc chloride flux. The strength of sleeve joints made with these solders, at room temperature and at elevated temperatures, was higher than that of joints made with pure lead and approached that of joints made with the lead-silver solders. From the standpoint of permanence of the bond between the solder and copper base, at elevated temperatures (250° F and above), the lead-cadmium-zinc solders were found to be superior to tin-base solders. From the standpoint of ease of application, the lead-cadmium-zinc solders are preferable to the lead-silver solders. Possible lack of an adequate supply of cadmium may be detrimental to a wide use of the lead-cadmium-zinc solders under present conditions. As the zinc content should not be over 0.5 percent, and apparently could be as low as 0.3 percent, it is not probable that the availability of zinc would be a significant factor in the use of these solders.

The (82–17.5–0.5) lead-cadmium-zinc alloy is close to the lead-cadmium eutectic and melts at practically a constant temperature (477° F). The lack of a melting range might not be a detriment to bit or machine soldering, but would cause difficulties in sweat soldering, for which a melting range, preferably one of at least 30° to 40° F, is desirable. With 14 percent of cadmium a melting range of about 7° F was obtained; with 12 percent of cadmium, the melting range would be about 15° F, which is satisfactory for most purposes. Further decrease in the cadmium content to widen the melting range would result in an undesirably high upper melting temperature.

V. SUMMARY

1. The results of a previous investigation established the fact that (50–50) tin-lead alloy and (95–5) tin-antimony alloy are satisfactory for use in soldered sleeve joints in copper tubing, provided the service temperature does not exceed 250° F. The (50–50) tin-lead solder meets the needs of general domestic plumbing satisfactorily, and the (95–5) tin-antimony

solder can be used in applications where higher strengths are necessary or where the presence of lead is not desired.

2. The present investigation supplemented the previous one, the principal aim being the finding of a solder satisfactory for continuous service at temperatures above 250° F. Lead-base alloys of the following typical compositions were used: (95–5) lead-tin; (60–39–1) lead-tin-antimony; (95.3–4.7) lead-silver; (97.2–2.8) lead-silver; (85.4–14.3–0.3) lead-cadmium-zinc; (82–17.5–0.5) lead-cadmium-zinc; and high-purity lead.

3. The types of specimens and the testing procedures used were essentially identical with those of the previous investigation. Short-time tensile tests at room temperature (85° F) and long-time continuous tensile-loading tests at temperatures ranging from room temperature (85° F) to 325° F were carried out. Results of the latter type of test constitute a very important index of the merits of soft-soldered sleeve joints under service conditions at various temperatures. Data of this kind on all the solders investigated (including those of the first investigation) are given in tables 1 and 2.

4. Information concerning the tendency toward deterioration of the "bond" of a soldered joint as a result of structural changes at elevated temperatures is necessary in establishing a complete criterion for the evaluation of the permanence of soldered joints under service conditions involving elevated temperature. All of the solders that contained tin showed a tendency toward deterioration (weakening) of the bond, on long-continued exposure to temperatures above 250° F. This tendency was not observed in any of the joints made with lead-base (tin-free) solders. The maximum temperature recommended for joints made with solders containing tin, is therefore, 250° F.

5. Within the shear-stress limitations given (table 2), lead-silver solders and lead-cadmium-zinc solders of the typical compositions tested can be used with satisfaction at temperatures up to 325° F, although difficulty may be experienced in "sweat" soldering, as in making sleeve joints, with the alloys (97.5–2.5) lead-silver and (82–17.5–0.5) lead-cadmium-zinc, which are close to the eutectic in their composition and therefore remain molten over a relatively very short temperature interval. From the standpoint of ease of application, the lead-cadmium-zinc solders are somewhat superior to the lead-silver solders.

6. The use of lead as a commercial solder is limited by the difficult technique required in its application.

VI. SELECTED REFERENCES

[1] Arthur R. Maupin and William H. Swanger, Strength of Soft-soldered Joints in Copper Tubing, NBS Building Materials and Structures Report BMS58 (Sept. 1940).

[2] J. McKeown, *Creep of lead and lead alloys. Part I—Creep of virgin lead*, J. Inst. Metals **60**, 201 (1937).

[3] A. J. Phillips, *Some creep tests on lead and lead alloys*, Proc. Am. Soc. Testing Materials **36**, pt. 2, 170 (1936).

[4] B. S. Barham, *Soft solders for use at elevated temperatures*, Metal Ind. (London) **52**, 521 (1938).

[5] J. Neill Greenwood and Howard K. Worner, *Types of creep curve obtained with lead and its dilute alloys*, J. Inst. Metals **64**, 135 (1939).

[6] Herbert F. Moore, Bernard B. Betty, and Curtis W. Dollins, Investigation of Creep and Fracture of Lead and Lead Alloys for Cable Sheathing, Univ. Ill. Eng. Exp. Sta. Bul. 306 (1938).

VII. APPENDIX. RESULTS OF LONG-TIME LOADING TESTS ON JOINTS MADE WITH SOLDERS LISTED IN TABLE 1

The values given in table 2 and figure 1, in the main part of this report, were chosen as the maximum stresses on the soldered areas at which extensions at an increasing rate did not occur under constant tensile loads, maintained for 5,000 or more hours. The tests were conducted at room temperature (approximately 85° F), 250°, and 325° F. The specimens were made with suitable lengths of type-*L* hard-drawn copper tubing, ¾-inch nominal diameter, soldered into wrought-copper couplings. The bore depth in the joint was maintained at 0.87 ±0.01 inch and the diametral clearance at 0.004 ±0.0006 inch. The extensions were measured at suitable intervals, as described in the previous report [1]. The extensions, in thousandths of an inch for the individual specimens, are plotted against time, in hours, in the accompanying figures 2 to 13. Total extensions of less than 0.001 inch were considered to be not significant, and are not shown.

No curves are given for specimens soldered with the (60–39–1) lead-tin-antimony alloy for the test temperature of 325° F, because this temperature is only slightly below the lower melting temperature of the solder, and this solder is not recommended for use above 250° F.

The specimens made with the two lead-cadmium-zinc solders (fig. 10) were not tested at 250° F. Curves for

the specimens tested at room temperature (85° F.) are not shown. None of the specimens under stresses up to 740 pounds per square inch showed any extension at room temperature. Rapid failure occurred at stresses of about 900 pounds per square inch. It was concluded that the value 740 pounds per square inch was well on the safe side, although a slightly higher stress might be possible for this solder.

The curves, figures 7, 8, and 9, for the specimens made with the (95.3–4.7) lead-silver solder can also be considered as applying to the (97.2–2.8) lead-silver solder. A complete series of tests with the latter solder was not made, but the results on a few specimens showed close agreement with those obtained on the solder of higher silver content. Further justification for the conclusion that these two solders are practically equal in strength is the close agreement at 250° and 325° F between the curves, 2, 3, 4, and 5 of figure 1, for all of the lead-base solders used in this investigation. For this reason it is believed also that for practical purposes the strength values for the (96–4) lead-silver solder, recommended as probably the most suitable lead-silver solder, would agree closely with those given for the actual compositions used in this investigation.

Acknowledgment is made for assistance in the conduct of this investigation received from various members of the staff of the National Bureau of Standards, particularly the Division of Metallurgy. Acknowledgment is made also for helpful advice and suggestions received from T. E. Veltfort, manager, and J. S. McClenahan, assistant manager, Copper and Brass Research Association.

WASHINGTON, January 7, 1942.

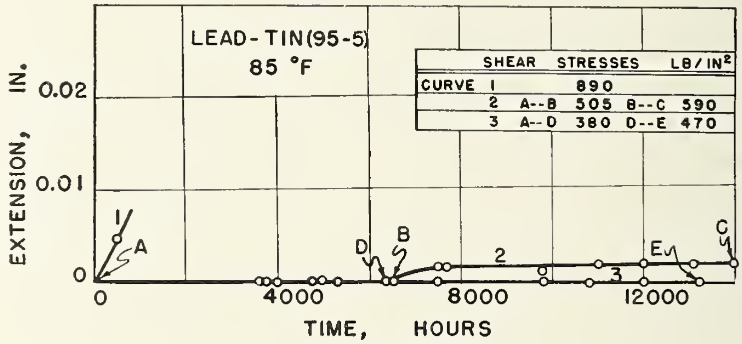

FIGURE 2.

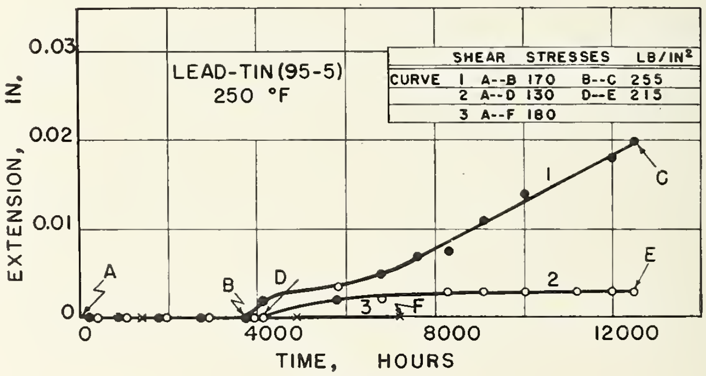

FIGURE 3.

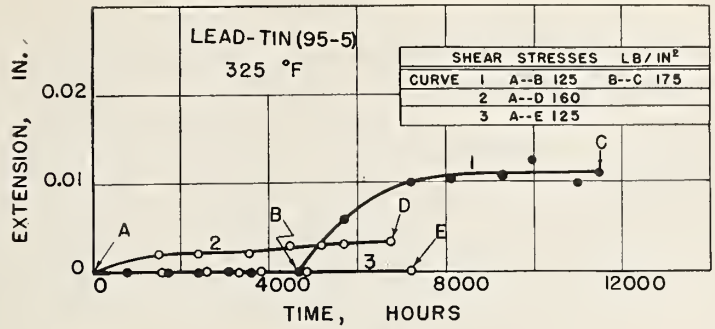

Figure 4.

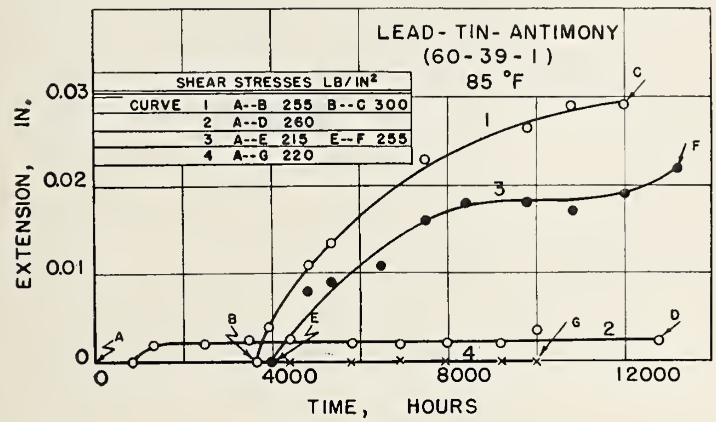

Figure 5.

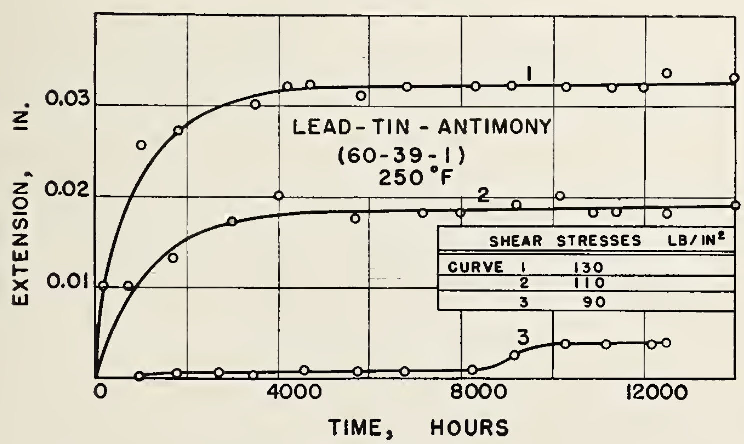

Figure 6.

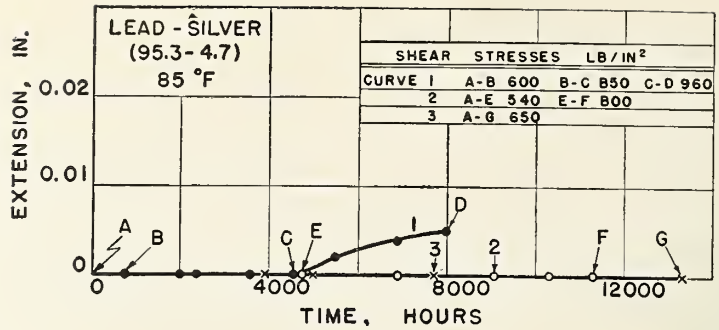

Figure 7.

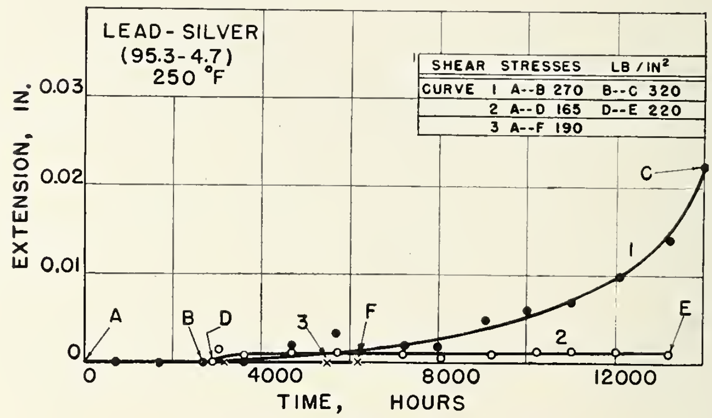

Figure 8.

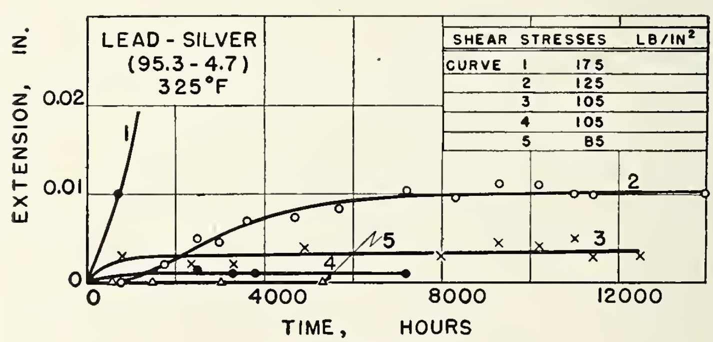

Figure 9.

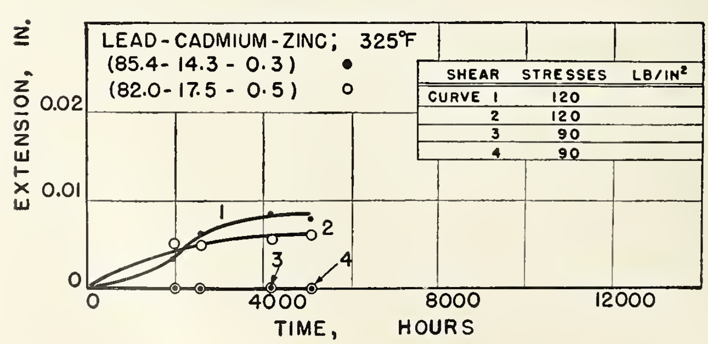

Figure 10.

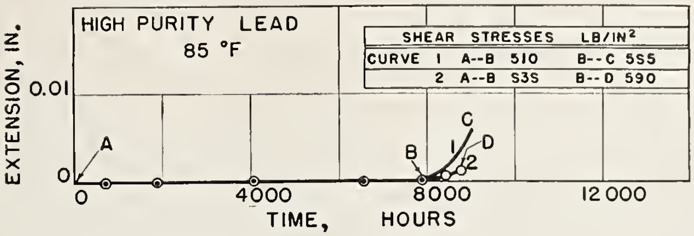

Figure 11.

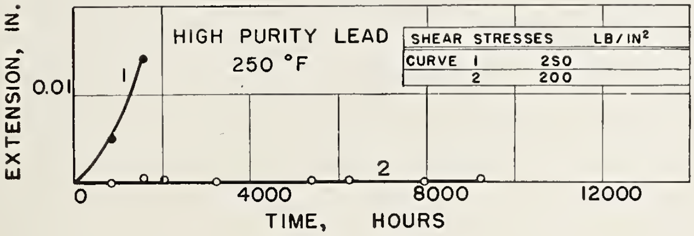

Figure 12.

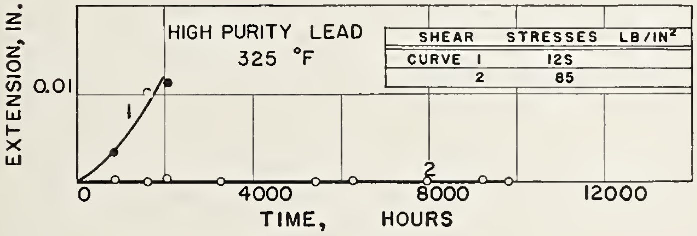

Figure 13.

BUILDING MATERIALS AND STRUCTURES REPORTS

On request, the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., will place your name on a special mailing list to receive notices of new reports in this series as soon as they are issued. There will be no charge for receiving such notices.

An alternative method is to deposit with the Superintendent of Documents the sum of $5.00, with the request that the reports be sent to you as soon as issued, and that the cost thereof be charged against your deposit. This will provide for the mailing of the publications without delay. You will be notified when the amount of your deposit has become exhausted.

If 100 copies or more of any paper are ordered at one time, a discount of 25 percent is allowed.

Send all orders and remittances to the *Superintendent of Documents, U. S. Government Printing Office, Washington, D. C.*

The following publications in this series are available by purchase from the Superintendent of Documents at the prices indicated:

BMS1	Research on Building Materials and Structures for Use in Low-Cost Housing	10¢
BMS2	Methods of Determining the Structural Properties of Low-Cost House Constructions	10¢
BMS3	Suitability of Fiber Insulating Lath as a Plaster Base	10¢
BMS4	Accelerated Aging of Fiber Building Boards	10¢
BMS5	Structural Properties of Six Masonry Wall Constructions	15¢
BMS6	Survey of Roofing Materials in the Southeastern States	15¢
BMS7	Water Permeability of Masonry Walls	10¢
BMS8	Methods of Investigation of Surface Treatment for Corrosion Protection of Steel	10¢
BMS9	Structural Properties of the Insulated Steel Construction Co.'s "Frameless-Steel" Constructions for Walls, Partitions, Floors, and Roofs	10¢
BMS10	Structural Properties of One of the "Keystone Beam Steel Floor" Constructions Sponsored by the H. H. Robertson Co	10¢
BMS11	Structural Properties of the Curren Fabrihome Corporation's "Fabrihome" Constructions for Walls and Partitions	10¢
BMS12	Structural Properties of "Steelox" Constructions for Walls, Partitions, Floors, and Roofs Sponsored by Steel Buildings, Inc	15¢
BMS13	Properties of Some Fiber Building Boards of Current Manufacture	10¢
BMS14	Indentation and Recovery of Low-Cost Floor Coverings	10¢
BMS15	Structural Properties of "Wheeling Long-Span Steel Floor" Construction Sponsored by Wheeling Corrugating Co	10¢
BMS16	Structural Properties of a "Tilecrete" Floor Construction Sponsored by Tilecrete Floors, Inc	10¢
BMS17	Sound Insulation of Wall and Floor Constructions	10¢
Supplement to BMS17, Sound Insulation of Wall and Floor Constructions		5¢
BMS18	Structural Properties of "Pre-Fab" Constructions for Walls, Partitions, and Floors Sponsored by the Harnischfeger Corporation	10¢
BMS19	Preparation and Revision of Building Codes	15¢
BMS20	Structural Properties of "Twachtman" Constructions for Walls and Floors Sponsored by Connecticut Pre-Cast Buildings Corporation	10¢
BMS21	Structural Properties of a Concrete-Block Cavity-Wall Construction Sponsored by the National Concrete Masonry Association	10¢
BMS22	Structural Properties of "Dun-Ti-Stone" Wall Construction Sponsored by the W. E. Dunn Manufacturing Co	10¢
BMS23	Structural Properties of a Brick Cavity-Wall Construction Sponsored by the Brick Manufacturers Association of New York, Inc	10¢
BMS24	Structural Properties of a Reinforced-Brick Wall Construction and a Brick-Tile Cavity-Wall Construction Sponsored by the Structural Clay Products Institute	10¢
BMS25	Structural Properties of Conventional Wood-Frame Constructions for Walls, Partitions, Floors, and Roofs	15¢
BMS26	Structural Properties of "Nelson Pre-Cast Concrete Foundation" Wall Construction Sponsored by the Nelson Cement Stone Co., Inc	10¢
BMS27	Structural Properties of "Bender Steel Home" Wall Construction Sponsored by The Bender Body Co	10¢
BMS28	Backflow Prevention in Over-Rim Water Supplies	10¢
BMS29	Survey of Roofing Materials in the Northeastern States	10¢
BMS30	Structural Properties of a Wood-Frame Wall Construction Sponsored by the Douglas Fir Plywood Association	10¢
BMS31	Structural Properties of "Insulite" Wall and "Insulite" Partition Constructions Sponsored by The Insulite Co	15¢

[List continued on cover page IV]

BUILDING MATERIALS AND STRUCTURES REPORTS

[Continued from cover page III]